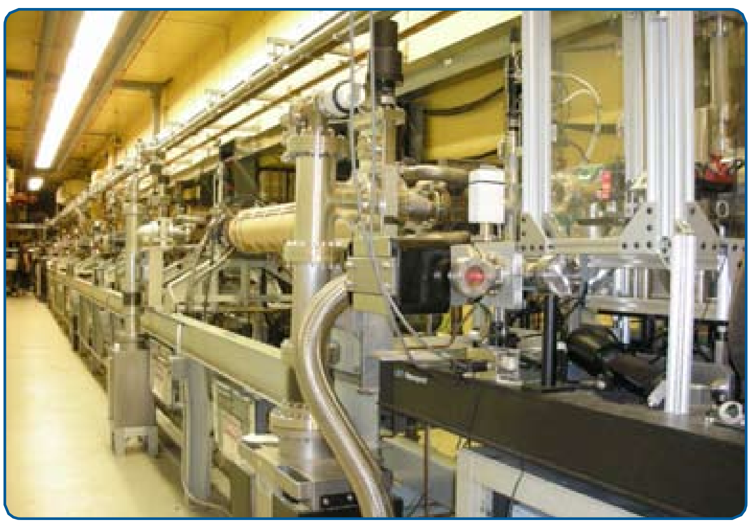
NIF
National Ignition Facility

Photon Science & Applications

The Photon Science and Applications (PS&A) program at Lawrence Livermore National Laboratory (LLNL) is a mission-oriented research and development organization that aims to innovate and construct frontier photon capabilities and to address with them important national needs consistent with LLNL's missions. PS&A leads in the development of large-scale photon systems and in the execution of photo-based projects for energy, defense, homeland and stockpile security, basic science and industrial competitiveness. Specific areas of PS&A's technical expertise include petawatt peak-power and megawatt average-power laser technology, ultrashort-duration X-ray and laser-like gamma-ray sources, meter-scale diffractive optics and the development of advanced laser crystals and transparent ceramics.



T-REX Gamma-ray Source

T-REX is LLNL's first MEGa-ray system and is the world's highest peak brightness MeV-class light source.

Laser-based X-rays and Gamma-rays

The advanced radiography and energetic systems program element (ARES) of PS&A develops technology required for cutting-edge, short-duration X-ray radiography on NIF and laser-like, mono-energetic gamma-ray (MEGa-ray) source technologies for relevant Lawrence Livermore National Laboratory, National Nuclear Security Administration and U.S. Department of Energy missions.

MEGa-ray sources and related nuclear missions concepts were conceived of and realized over the course of the last five years. MEGa-rays created by Compton scattering short-duration laser pulses from relativistic electrons are a new class of light source with extraordinary qualities. The peak brightness of a MEGa-ray pulse can be 15 orders beyond any other man-made light in the million-electron-volt (MeV) spectral range. This revolutionary leap enables new solutions to an astonishingly wide variety of critical and near-term national needs. MEGa-rays can be used to solve the grand challenge of finding and detecting highly enriched uranium, provide a unique tool for performing quantitative assay and imaging of nuclear waste and nuclear fuel systems, enable in-situ 3-D isotope-specific images of aging nuclear weapons, permit fundamental advances in stockpile science by providing picosecond temporal snapshots of isotope positions and velocities in turbulent mix systems, and provide a fundamental new tool for understanding and reinvigorating nuclear physics.

NIF's Advanced Radiographic Capability (ARC) uses and extends LLNL's expertise in high-energy petawatt lasers to enable multi-frame, hard-X-ray radiography of imploding NIF capsules – a capability which is critical to the success of NIF's mission.

The system will also play a critical role in prospective studies of fast-ignition physics on NIF. Moreover, by coherent addition of pulses from multiple ARC apertures – similar to how modern astronomy uses coherent addition of light from many small mirrors to achieve the focusing resolution and light-gathering power of a much larger mirror – future additions to NIF-ARC may utilize coherent addition of pulses to produce exawatt-class (10^{18} watt) peak powers and ultra-high focal intensities unachievable from single-aperture lasers.

PHOTON SCIENCE

High-power Lasers for Clean Energy

PS&A's fusion energy systems and science (FESS) program element develops the high-energy, high-average-power laser technologies that will be required to generate electric power from laser-based inertial fusion. Fusion is the process by which our sun and other stars convert or "burn" hydrogen (the lightest element) and produce helium (the next lightest element). The fusion of hydrogen releases immense amounts of energy. Conditions needed to burn fusion fuel include extremely high temperatures and pressures. The controlled release of fusion, or thermonuclear energy, in the laboratory remains an alluring goal due to its potential as a source of unlimited, environmentally friendly energy for humankind.

The Mercury Laser

Mercury is the world's highest-energy and power, nanosecond-pulse, diode-pumped laser.

The two main approaches to achieving controlled release of thermonuclear energy in the laboratory are magnetic fusion and inertial confinement fusion. The National Ignition Facility (NIF) is designed to demonstrate fusion by inertial confinement. Inertial confinement fusion involves the rapid compression of small fuel capsules (containing isotopes of hydrogen) to reach densities and temperatures greater than those in the core of the sun. When the correct temperature and density are reached (100 million kelvins and a density 100 times that of lead) the fuel capsule ignites and then burns while confined by its own inertia. NIF is expected to demonstrate fusion ignition – the release of more energy via fusion burn than the laser energy used to initiate ignition. NIF is able to fire its laser at a rate of a shot every few hours. For laser inertial fusion energy (LIFE) to become practical, targets will have to be ignited at a rate of several shots per second.

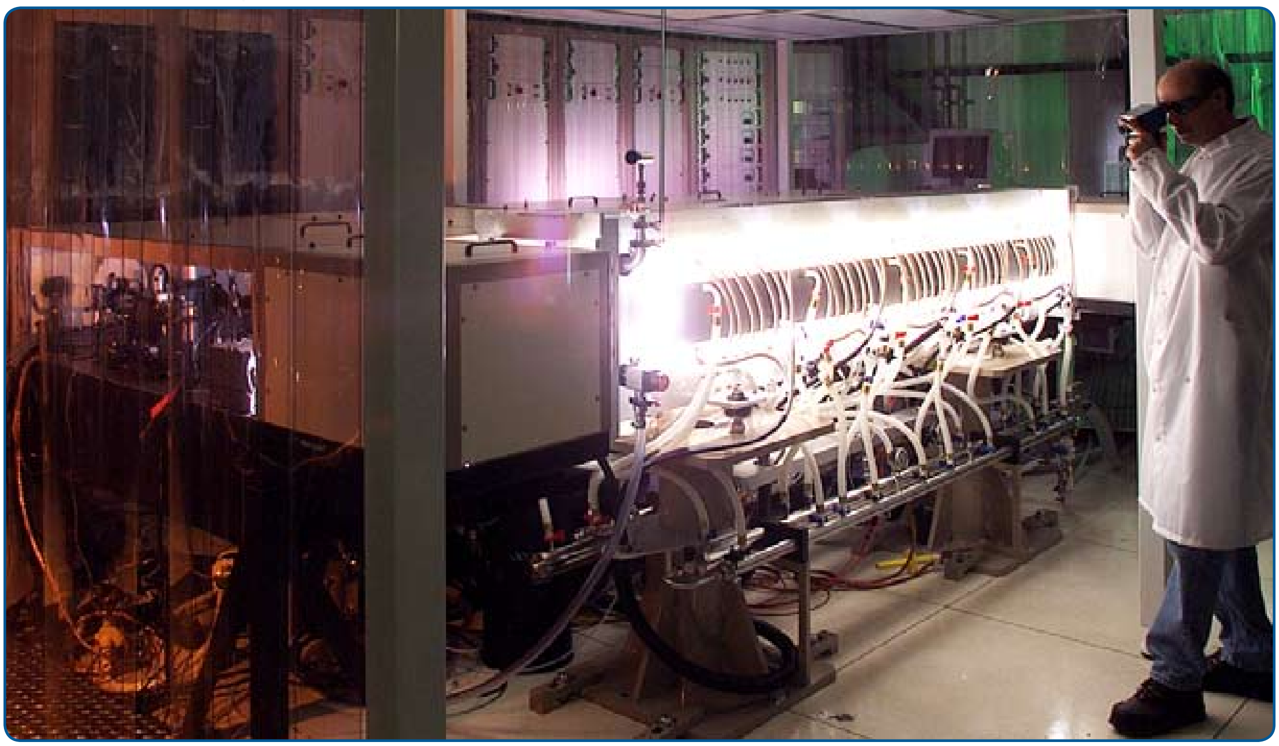
PS&A's efforts to develop the necessary laser technology for LIFE include the development of low-cost, high-energy, high-efficiency laser drivers with repetition rates of several times a second. The Mercury laser project has been an important part of this PS&A mission. The Mercury laser was constructed as scalable diode-pumped laser test bed and has demonstrated the viability of diode-pumped laser technology to produce energetic laser pulses at repetition rates of ten shots per second with the electrically efficiency required for commercial laser fusion power. While the Mercury laser has generated only a small fraction (1/30,000) of the peak power of NIF, because of its high repetition rate it has operated at a higher average power. Mercury currently holds the world record for nanosecond pulse energy from a diode-pumped laser system. The design of Mercury takes advantage of the optical technology advances developed for NIF and of LLNL's expertise in high- power diode-laser arrays. Since the mid-1980s, LLNL has been the world leader in the development of high-power semiconductor diode-laser arrays, including advances in diode-laser packaging, radiance conditioning and efficient pump light delivery.

Transformational Capabilities for Defense

The laser weapons enterprise of the 21st century in many ways parallels that of the nuclear weapons enterprise of the 20th century. This enterprise requires end-to-end dedication to laser systems design, engineering and production for specific applications and missions, experimentally-validated first-principles understanding of weapon lethality and vulnerability, and diligent evaluation and prediction of the emergence of potential threats.

The directed energy systems and technology (DEST) program element of PS&A is developing "electric" laser systems that will enable the tactical and strategic laser missions of the 21st century. In the last 15 years, LLNL's technological advances and innovations in scaled, semiconductor diode-laser pump arrays and large-aperture transparent ceramic gain slabs have made possible much more efficient and less massive all-electric laser systems with power levels and beam characteristics suitable to a wide variety of defense applications. Unique PS&A electric lasers for defense missions include tailored-aperture ceramic lasers (TACL), nano-structured optical-fiber (NSOF) lasers and diode-pumped alkali lasers (DPAL), the latter of which were invented at LLNL. The world's largest ceramic laser gain slabs are used in LLNL's solid-state heat-capacity laser. This system consistently provides high power beams for laser interaction studies and has illustrated the potential of diode-pumped lasers to meet the needs of both tactical and strategic laser missions in the coming decade.

The emergence of industrial systems with near-military power levels creates the potential for new weapons proliferation and terrorist problems that need to be assessed. PS&A's unique knowledge of electric laser technology, high-power laser optics and advanced laser materials, along with its broad experience in both government and commercial industry programs, will be important to understanding and anticipating these new threats. The combination of PS&A's laboratories with high-power laser capabilities and LLNL's world-leading computation infrastructure enables a science-based, predictive understanding of laser weapons effects, countermeasures and analysis of emerging threats.



Flashlamp-pumped Heat Capacity Laser

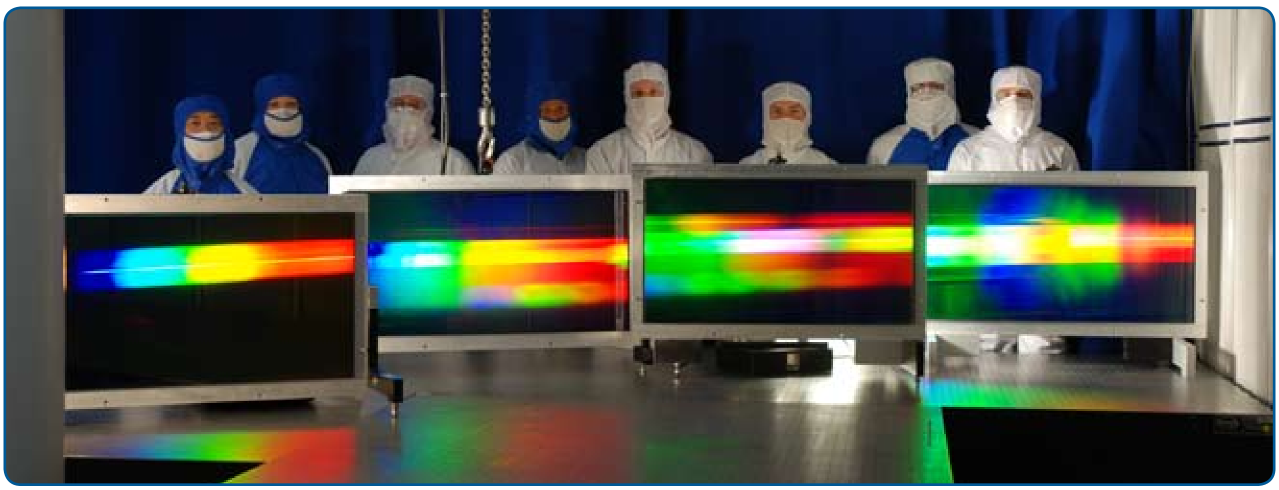
PS&A has developed world-record average-power single-aperture solid-state lasers.

Critical and Enabling Optical Technologies

PS&A's advanced optical components and technologies (AOCT) program element develops, creates and provides critical optical components for laser-based missions at LLNL. Past projects focused on kinoform phase plates for LLNL's Nova laser and on large-area, submicron-pitch holographic diffraction gratings for LLNL's Petawatt (10^{15} watt) ultrashort pulse laser. Today, the AOCT team designs and fabricates a variety of custom diffractive optics for researchers worldwide. Included are multilayer dielectric and gold-overcoated master diffraction gratings for pulse compression (up to one meter in diameter); ion-beam-etched transmission gratings; wet-etched gratings; multilevel-etched Fresnel lenses and phase plates (up to meter-scale); segmented Fresnel lenses (multiple-meter scale); continuous-contour optics such as phase plates fabricated by wet-etch figuring; replicated polymeric freestanding and attached diffractive films (at 50-centimeters scale); and many other specialty optics.

Traditionally LLNL has had world-leading efforts in fabrication of large-area laser and non-linear optical crystals. Recently PS&A has also developed an ability to produce device-scale, laser-quality transparent ceramic optics with an emphasis on designer laser materials and components that will enable new, compact and efficient laser architectures for energy and defense applications.

AOCT's efforts have been essential to expanding PS&A's international leadership of average- power, high-peak-power and high-photon-energy systems and applications.



Multilayer Dielectric Diffraction Gratings

Diffraction gratings produced for NIF's Advanced Radiographic Capability petawatt laser have record size, damage resistance and efficiency.